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Parameter Identification Flight Test Maneuvers for Closed Loop Modeling of the F-18 High Alpha Research Vehicle (HARV)

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Abstract

Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were designed for closed loop parameter identification purposes, specifically for longitudinal and lateral linear model parameter estimation at 5, 20, 30, 45, and 60 degrees angle of attack, using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Thrust Vectoring (TV) mode. Each maneuver is to be realized by applying square wave inputs to specific pilot station controls using the On-Board Excitation System (OBES). Maneuver descriptions and complete specifications of the time / amplitude points defining each input are included, along with plots of the input time histories.

Nomenclature

ANSER	Actuated Nose Strakes for Enhanced Rolling
h	altitude, feet
OBES	On-Board Excitation System
TV	thrust vectoring
t	time, seconds
V	airspeed, feet/second
α	angle of attack, degrees
η_a	lateral stick deflection in inches, positive for right stick
η_e	longitudinal stick deflection in inches, positive for aft deflection from neutral
η_r	rudder pedal force in pounds, positive for right rudder

subscripts

o	nominal or trim value

I. Introduction

The F-18 High Alpha Research Vehicle (HARV) is a highly instrumented research aircraft used in the NASA High Alpha Technology Program[1]. Objectives for this program include validating advanced control system design techniques in flight.

In this work, the technique described in references [2] and [3] was used to design flight test maneuvers consisting of optimal closed loop square wave inputs. These square wave inputs are to be applied directly to pilot station controls by the On-Board Excitation System (OBES)[4]. The optimal input design technique uses dynamic programming to compute globally optimal square wave inputs for model parameter estimation experiments, based on *a priori* dynamic models. Linear *a priori* dynamic models were obtained from an F-18 HARV nonlinear simulation[5]. The maneuvers were designed specifically to collect flight data with maximum information content for dynamic modeling purposes.

Specific objectives addressed by the maneuvers specified in this document are:

1. Identify closed loop longitudinal and lateral linear dynamic models for validation of the control law design methods implemented by the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Thrust Vectoring (TV) mode.

2. Identify closed loop longitudinal and lateral linear models for comparison and correlation with military specifications for flying qualities of piloted aircraft, pilot comments and handling qualities ratings.

3. Update and verify existing aerodynamic models.

The purpose of this report is to document the specifications for the maneuvers designed to achieve the above objectives.

II. Maneuver Descriptions

There are ten (10) optimal square wave input maneuvers described in this report. The maneuvers can be divided into two groups:

1. Five (5) maneuvers for longitudinal closed loop model identification using the OBES system.
2. Five (5) maneuvers for lateral-directional closed loop model identification using the OBES system.

All maneuvers are to be flown using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Thrust Vectoring (TV) mode[6,7]. Control definitions and sign conventions are given above in the **Nomenclature** section. Detailed descriptions of the maneuvers in each group appear below, with numbering corresponding to that given above.

1. This group of five maneuvers is for identifying closed loop longitudinal dynamic models and for control law design validation. Initial flight conditions are trim angle of attack 5, 20, 30, 45, and 60 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode. These maneuvers involve pure longitudinal stick deflection by the On-Board Excitation System (OBES).

Optimal longitudinal stick input specifications for $\alpha = 5, 20, 30, 45$ and 60 degrees are given in Tables 1–5, respectively. Each input specification consists of the initial flight condition for the maneuver, followed by a tabulation of the time / amplitude points for the input. Figures 1–5 show time histories for the optimal longitudinal stick inputs at $\alpha = 5, 20, 30, 45$ and 60 degrees, respectively. Pilot station controls for the initial steady flight condition are defined as zero for the inputs shown in the figures. The inputs included a rate limit of 12 inches per second on the longitudinal stick input to reduce the effects of control surface rate limiting and to model human pilot capability.

Each maneuver in this group is to be flown two (2) times, for a total of ten (10) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 30 seconds. Estimated flight time for this set of maneuvers (including repeats) is approximately 25 minutes.

2. This group of five maneuvers is for identifying closed loop lateral-directional dynamic models and for control law design validation. Initial flight conditions are trim angle of attack 5, 20, 30, 45, and 60 degrees and approximately 25,000 feet altitude, with the ANSER control law in TV mode.

These maneuvers involve rudder pedal and lateral stick deflection by the On-Board Excitation System (OBES).

Optimal rudder pedal and lateral stick input specifications for $\alpha = 5, 20, 30, 45$ and 60 degrees are given in Tables 6–10, respectively. Each input specification consists of the initial flight condition for the maneuver, followed by a tabulation of the time / amplitude points for the inputs. Figures 6–10 show time histories for the optimal rudder pedal and lateral stick inputs at $\alpha = 5, 20,$ 30, 45 and 60 degrees, respectively. Pilot station controls for the initial steady flight condition are defined as zero for the inputs shown in the figures. The inputs included a rate limit of approximately 425 pounds per second on the rudder pedal input and approximately 16 inches per second on the lateral stick input to reduce the effects of control surface rate limiting and to model human pilot capabilities. The stated rate limits are approximate because the physical deflections of the rudder pedal and lateral stick are nonlinear functions of the control system input units which were used in the models for designing the experiment.

Each maneuver in this group is to be flown two (2) times, for a total of ten (10) runs. Each run should be preceded by at least two seconds of steady trimmed flight, and followed by at least two seconds of free response before the pilot takes action to control the aircraft. The duration of each maneuver is 20 seconds, and consists of 10 seconds of pure rudder pedal input followed by 10 seconds of pure lateral stick input. Estimated flight time for this set of maneuvers (including repeats) is approximately 25 minutes.

III. Acknowledgments

This research was conducted at the NASA Langley Research Center under NASA contract NAS1-19000.

IV. References

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V. Input Specification Tables

LONGITUDINAL CLOSED LOOP OPTIMAL INPUT MANEUVERS

F-18 HARV using the ANSER Control Law in Thrust Vectoring Mode

5 α OPTIMAL LONGITUDINAL STICK MANEUVER

Initial Conditions

$\alpha_o = 5°$

V_o = 370 knots h_o = 25,000 feet

$|\text{OBES } \eta_e|_{max}$ = 0.5 inch

Table 1

(Figure 1)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
0	0
0.100	0.5
1.200	0.5
1.375	–0.5
1.800	–0.5
1.975	0.5
3.000	0.5
3.175	–0.5
4.200	–0.5
4.375	0.5
5.400	0.5
5.575	–0.5
6.900	–0.5
7.075	0.5
7.800	0.5
7.975	–0.5
9.300	–0.5
9.475	0.5
10.500	0.5
10.675	–0.5
11.700	–0.5

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
11.875	0.5
13.500	0.5
13.675	–0.5
14.700	–0.5
14.875	0.5
15.600	0.5
15.775	–0.5
17.400	–0.5
17.575	0.5
18.300	0.5
18.475	–0.5
19.500	–0.5
19.675	0.5
21.300	0.5
21.475	–0.5
22.200	–0.5
22.375	0.5
23.400	0.5
23.575	–0.5
25.200	–0.5
25.375	0.5

(cont.)

Table 1 (cont.)

(Figure 1)

OBES longitudinal stick

Time (seconds)	OBES η_e (inch)
25.800	0.5
25.975	–0.5
27.300	–0.5
27.475	0.5
28.500	0.5
28.675	–0.5
29.700	–0.5
29.800	0
30.000	0

20 α OPTIMAL LONGITUDINAL STICK MANEUVER

Initial Conditions

$\alpha_o = 20°$

V_o = 198 knots h_o = 25,000 feet

$|\text{OBES } \eta_e|_{max} = 1.0$ inch

Table 2

(Figure 2)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
0	0
0.100	–1
0.900	–1
1.075	1
1.800	1
1.975	–1
3.000	–1
3.175	1
4.200	1
4.375	–1
5.100	–1
5.200	0
5.400	0
5.500	1
6.600	1
6.775	–1
7.800	–1
7.975	1
8.700	1
8.875	–1
9.900	–1
10.000	0

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
10.200	0
10.300	1
11.400	1
11.575	–1
12.000	–1
12.175	1
13.200	1
13.375	–1
14.100	–1
14.275	1
15.300	1
15.400	0
15.600	0
15.700	–1
16.800	–1
16.975	1
18.000	1
18.175	–1
19.200	–1
19.375	1
19.800	1
19.975	–1

(cont.)

Table 2 (cont.)
(Figure 2)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
21.000	–1
21.100	0
21.300	0
21.400	–1
21.600	–1
21.775	1
21.900	1
22.075	–1
22.500	–1
22.600	0
22.800	0
22.900	–1
23.400	–1
23.500	0
23.700	0
23.800	1
24.900	1
25.075	–1
26.100	–1
26.200	0
26.400	0
26.500	1
27.600	1
27.775	–1
28.800	–1
28.975	1
29.700	1
29.800	0
30.000	0

30 α OPTIMAL LONGITUDINAL STICK MANEUVER

Initial Conditions

$\alpha_o = 30°$

V_o = 167 knots h_o = 25,000 feet

$|\text{OBES } \eta_e|_{max}$ = 1.0 inch

Table 3

(Figure 3)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
0	0
0.100	1
0.800	1
0.900	0
1.200	0
1.300	–1
1.600	–1
1.775	1
2.600	1
2.700	0
3.000	0
3.100	–1
3.800	–1
3.975	1
5.000	1
5.175	–1
6.400	–1
6.575	1
7.600	1
7.775	–1
9.000	–1
9.175	1

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
10.000	1
10.175	–1
11.200	–1
11.375	1
12.400	1
12.575	–1
13.600	–1
13.775	1
14.400	1
14.575	–1
15.600	–1
15.775	1
16.200	1
16.375	–1
17.200	–1
17.300	0
17.800	0
17.900	–1
18.200	–1
18.375	1
19.400	1
19.575	–1

(cont.)

Table 3 (cont.)

(Figure 3)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
20.600	–1
20.775	1
22.000	1
22.175	–1
23.200	–1
23.375	1
24.600	1
24.775	–1
25.800	–1
25.975	1
27.000	1
27.175	–1
28.200	–1
28.375	1
29.200	1
29.300	0
30.000	0

45 α OPTIMAL LONGITUDINAL STICK MANEUVER

Initial Conditions

$\alpha_o = 45°$

V_o = 156 knots h_o = 25,000 feet

$|\text{OBES } \eta_e|_{max}$ = 1.0 inch

Table 4

(Figure 4)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
0	0
0.100	–1
0.900	–1
1.075	1
1.500	1
1.600	0
2.100	0
2.200	–1
3.000	–1
3.175	1
4.200	1
4.375	–1
5.400	–1
5.575	1
6.900	1
7.075	–1
7.800	–1
7.900	0
8.100	0
8.200	1
9.300	1
9.475	–1

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
10.200	–1
10.375	1
11.400	1
11.575	–1
12.600	–1
12.700	0
12.900	0
13.000	1
14.100	1
14.275	–1
15.300	–1
15.475	1
16.500	1
16.600	0
16.800	0
16.900	–1
18.000	–1
18.175	1
19.200	1
19.375	–1
20.100	–1
20.275	1

(cont.)

Table 4 (cont.)

(Figure 4)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
21.300	1
21.475	–1
22.200	–1
22.375	1
23.400	1
23.575	–1
24.600	–1
24.775	1
25.500	1
25.675	–1
26.700	–1
26.875	1
27.300	1
27.475	–1
28.200	–1
28.300	0
28.500	0
28.600	1
28.800	1
28.975	–1
29.700	–1
29.800	0
30.000	0

60 α OPTIMAL LONGITUDINAL STICK MANEUVER

Initial Conditions

$\alpha_o = 60°$

$V_o = 163$ knots $\qquad h_o = 25{,}000$ feet

$|\text{OBES} \cdot \eta_e|_{max} = 1.0$ inch

Table 5

(Figure 5)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
0	0
0.100	1
0.675	1
0.775	0
0.900	0
1.000	1
1.350	1
1.450	0
2.025	0
2.125	1
2.475	1
2.650	–1
2.700	–1
2.875	1
3.150	1
3.325	–1
3.375	–1
3.475	0
3.825	0
3.925	1
4.050	1
4.150	0

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
4.275	0
4.375	–1
4.950	–1
5.050	0
5.175	0
5.275	1
5.625	1
5.800	–1
5.850	–1
5.950	0
6.075	0
6.175	–1
6.975	–1
7.075	0
7.200	0
7.300	1
7.650	1
7.750	0
7.875	0
7.975	–1
9.450	–1
9.550	0

(cont.)

Table 5 (cont.)

(Figure 5)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
9.675	0
9.775	1
10.125	1
10.225	0
10.350	0
10.450	–1
11.925	–1
12.100	1
12.600	1
12.700	0
12.825	0
12.925	–1
15.750	–1
15.850	0
15.975	0
16.075	–1
16.875	–1
16.975	0
17.100	0
17.200	–1
17.775	–1
17.950	1
18.000	1
18.100	0
18.225	0
18.325	1
18.450	1
18.625	–1
19.350	–1
19.525	1

(cont.)

OBES longitudinal stick

Time (seconds)	OBES η_e (inches)
21.375	1
21.550	–1
21.825	–1
22.000	1
24.300	1
24.475	–1
25.425	–1
25.600	1
26.775	1
26.950	–1
27.900	–1
28.000	0
28.125	0
28.225	1
29.250	1
29.425	–1
29.700	–1
29.800	0
30.000	0

LATERAL CLOSED LOOP OPTIMAL INPUT MANEUVERS

F-18 HARV using the ANSER Control Law in Thrust Vectoring Mode

5 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$\alpha_o = 5°$

$V_o = 370$ knots $h_o = 25{,}000$ feet

$|\text{OBES } \eta_r|_{max} = 70.054$ pounds $|\text{OBES } \eta_a|_{max} = 1.292$ inches

Table 6

(Figure 6)

OBES rudder pedal

Time (seconds)	OBES η_r (pounds)
0	0
0.175	-70.054
1.200	-70.054
1.525	70.054
2.400	70.054
2.725	-70.054
2.800	-70.054
3.125	70.054
4.400	70.054
4.725	-70.054
5.200	-70.054
5.525	70.054
6.000	70.054
6.325	-70.054
6.800	-70.054
6.975	0
7.200	0
7.375	70.054
8.000	70.054
8.325	-70.054
8.800	-70.054
8.975	0
20.000	0

OBES lateral stick

Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.075	-1.292
10.800	-1.292
10.925	1.292
12.000	1.292
12.125	-1.292
13.200	-1.292
13.325	1.292
14.400	1.292
14.525	-1.292
15.600	-1.292
15.725	1.292
16.400	1.292
16.525	-1.292
17.200	-1.292
17.325	1.292
18.400	1.292
18.525	-1.292
19.200	-1.292
19.325	1.292
19.600	1.292
19.675	0
20.000	0

20 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$\alpha_o = 20°$

V_o = 198 knots h_o = 25,000 feet

$|\text{OBES } \eta_r|_{max}$ = 74.586 pounds $|\text{OBES } \eta_a|_{max}$ = 2.211 inches

Table 7

(Figure 7)

OBES rudder pedal

Time (seconds)	OBES η_r (pounds)
0	0
0.175	74.586
1.200	74.586
1.550	-74.586
2.000	-74.586
2.350	74.586
2.800	74.586
3.150	-74.586
4.400	-74.586
4.750	74.586
4.800	74.586
5.150	-74.586
6.000	-74.586
6.350	74.586
6.800	74.586
6.975	0
7.200	0
7.375	-74.586
8.000	-74.586
8.350	74.586
8.800	74.586
8.975	0
9.200	0
9.375	-74.586
10.000	-74.586
10.175	0
20.000	0

OBES lateral stick

Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.150	2.211
11.600	2.211
11.900	-2.211
12.400	-2.211
12.700	2.211
13.200	2.211
13.500	-2.211
14.800	-2.211
15.100	2.211
15.600	2.211
15.900	-2.211
16.400	-2.211
16.700	2.211
18.000	2.211
18.300	-2.211
19.200	-2.211
19.350	0
20.000	0

30 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$\alpha_o = 30°$

$V_o = 167$ knots $\qquad h_o = 25{,}000$ feet

$|\text{OBES } \eta_r|_{max} = 79.034$ pounds $\qquad |\text{OBES } \eta_a|_{max} = 2.211$ inches

Table 8

(Figure 8)

OBES rudder pedal

Time (seconds)	OBES η_r (pounds)
0	0
0.200	-79.034
0.800	-79.034
1.000	0
1.200	0
1.400	-79.034
1.600	-79.034
1.800	0
2.000	0
2.200	-79.034
2.400	-79.034
2.775	79.034
3.600	79.034
3.800	0
4.000	0
4.200	-79.034
5.200	-79.034
5.575	79.034
6.400	79.034
6.775	-79.034
7.600	-79.034
7.975	79.034
8.800	79.034
9.175	-79.034
9.600	-79.034
9.800	0
20.000	0

OBES lateral stick

Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.150	2.211
11.600	2.211
11.900	-2.211
13.600	-2.211
13.900	2.211
14.800	2.211
15.100	-2.211
16.000	-2.211
16.300	2.211
18.000	2.211
18.300	-2.211
19.600	-2.211
19.750	0
20.000	0

45 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$\alpha_o = 45°$

V_o = 156 knots h_o = 25,000 feet

$|\text{OBES } \eta_r|_{max}$ = 81.227 pounds $|\text{OBES } \eta_a|_{max}$ = 2.211 inches

Table 9

(Figure 9)

OBES rudder pedal

Time (seconds)	OBES η_r (pounds)
0	0
0.200	79.034
0.800	79.034
1.000	0
1.600	0
1.800	79.034
2.400	79.034
2.775	-79.034
3.600	-79.034
3.975	79.034
4.800	79.034
5.000	0
5.200	0
5.400	-79.034
5.600	-79.034
5.975	79.034
6.000	79.034
6.375	-79.034
7.200	-79.034
7.575	79.034
8.400	79.034
8.600	0
8.800	0
9.000	-79.034
10.000	-79.034
10.200	0
20.000	0

OBES lateral stick

Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.175	-2.318
11.600	-2.318
11.925	2.318
14.800	2.318
14.975	0
15.200	0
15.375	-2.318
18.000	-2.318
18.325	2.318
19.600	2.318
19.775	0
20.000	0

60 α OPTIMAL RUDDER PEDAL / LATERAL STICK MANEUVER

Initial Conditions

$\alpha_o = 60°$

$V_o = 163$ knots $\qquad h_o = 25{,}000$ feet

$|\text{OBES } \eta_r|_{\max} = 81.227$ pounds $\qquad |\text{OBES } \eta_a|_{\max} = 2.421$ inches

Table 10

(Figure 10)

OBES rudder pedal

Time (seconds)	OBES η_r (pounds)
0	0
0.200	79.034
0.800	79.034
1.175	-79.034
1.200	-79.034
1.400	0
1.600	0
1.800	79.034
2.800	79.034
3.175	-79.034
4.000	-79.034
4.375	79.034
4.800	79.034
5.175	-79.034
6.400	-79.034
6.600	0
6.800	0
7.000	79.034
7.600	79.034
7.800	0
8.000	0
8.200	-79.034
9.200	-79.034
9.575	79.034
10.000	79.034
10.200	0
20.000	0

OBES lateral stick

Time (seconds)	OBES η_a (inches)
0	0
10.000	0
10.175	-2.421
11.200	-2.421
11.550	2.421
14.000	2.421
14.175	0
14.400	0
14.575	-2.421
16.000	-2.421
16.350	2.421
17.200	2.421
17.375	0
17.600	0
17.775	-2.421
19.600	-2.421
19.775	0
20.000	0

VI. Control Time Histories

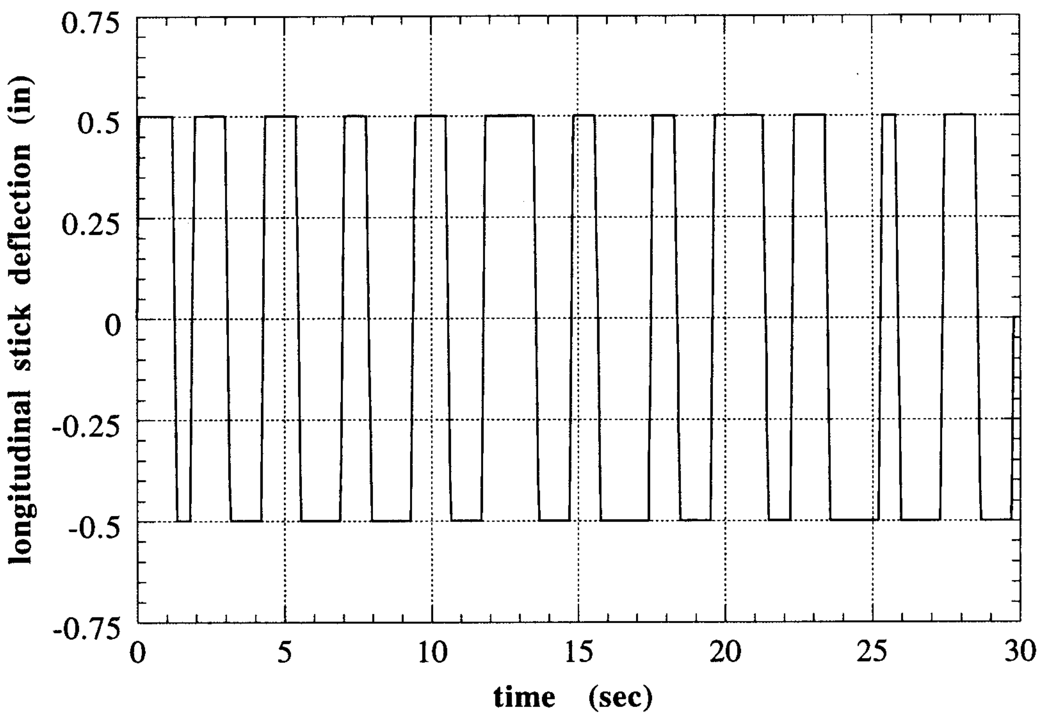


Figure 1 F-18 HARV Optimal Longitudinal Stick Input, $\alpha = 5$ degrees

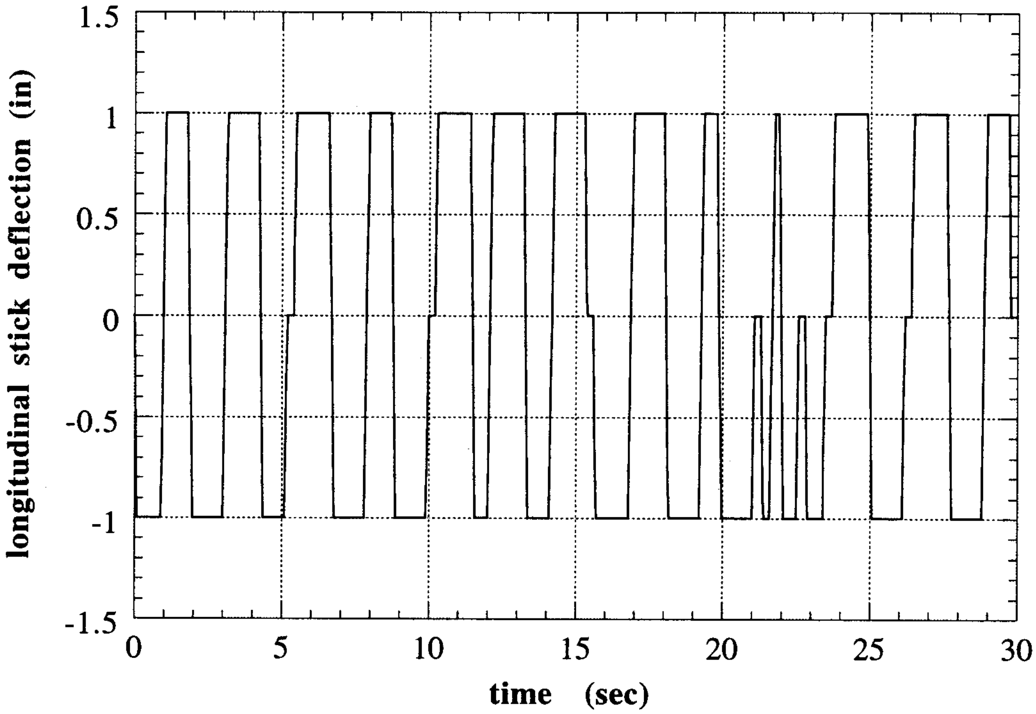


Figure 2 F-18 HARV Optimal Longitudinal Stick Input, $\alpha = 20$ degrees

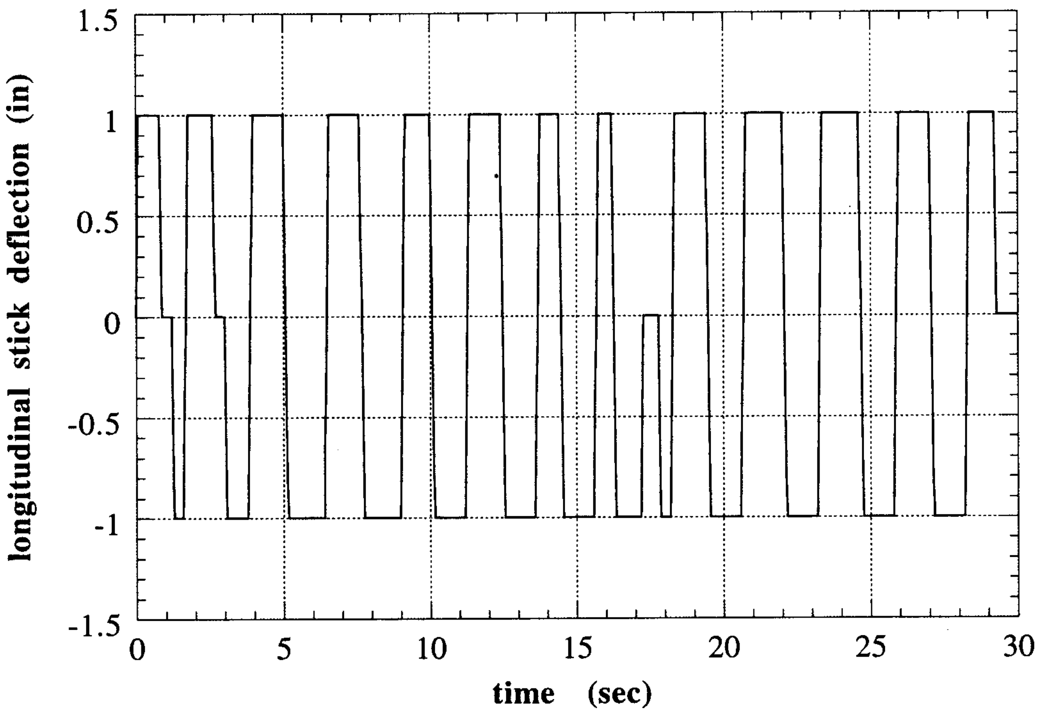


Figure 3 F-18 HARV Optimal Longitudinal Stick Input, $\alpha = 30$ degrees

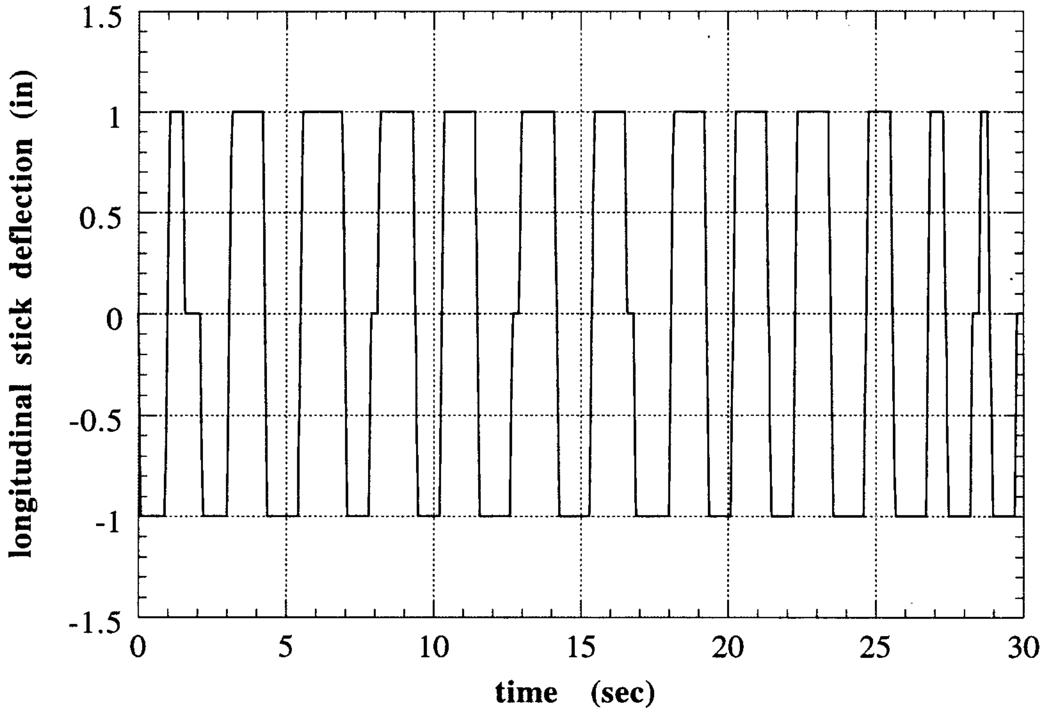


Figure 4 F-18 HARV Optimal Longitudinal Stick Input, $\alpha = 45$ degrees

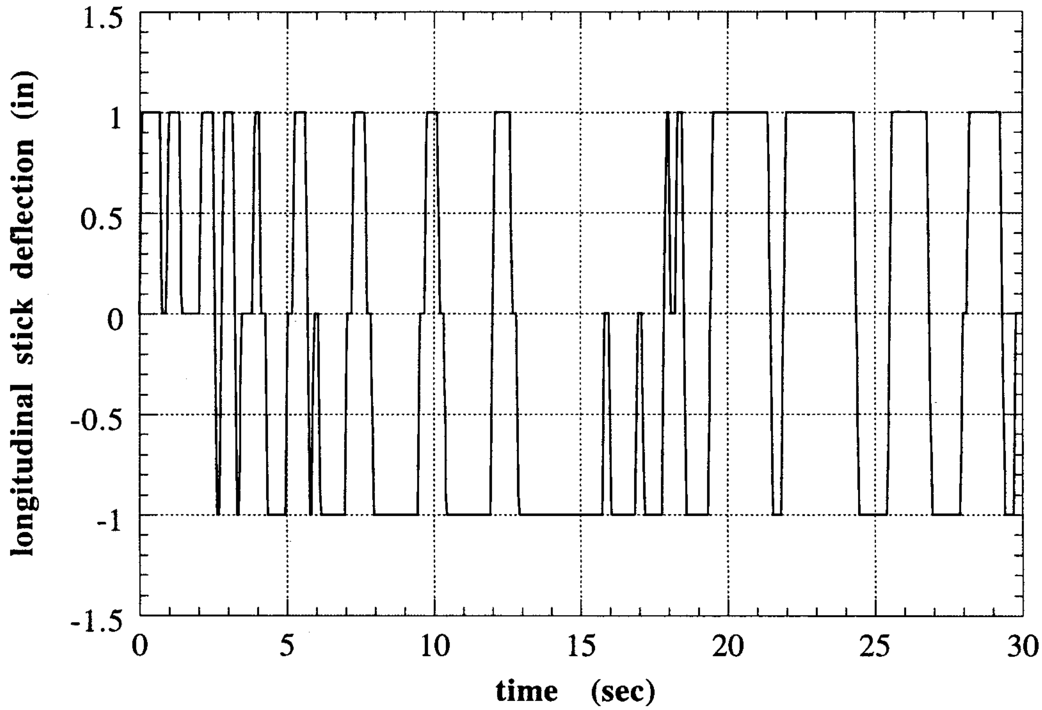


Figure 5 F-18 HARV Optimal Longitudinal Stick Input, $\alpha = 60$ degrees

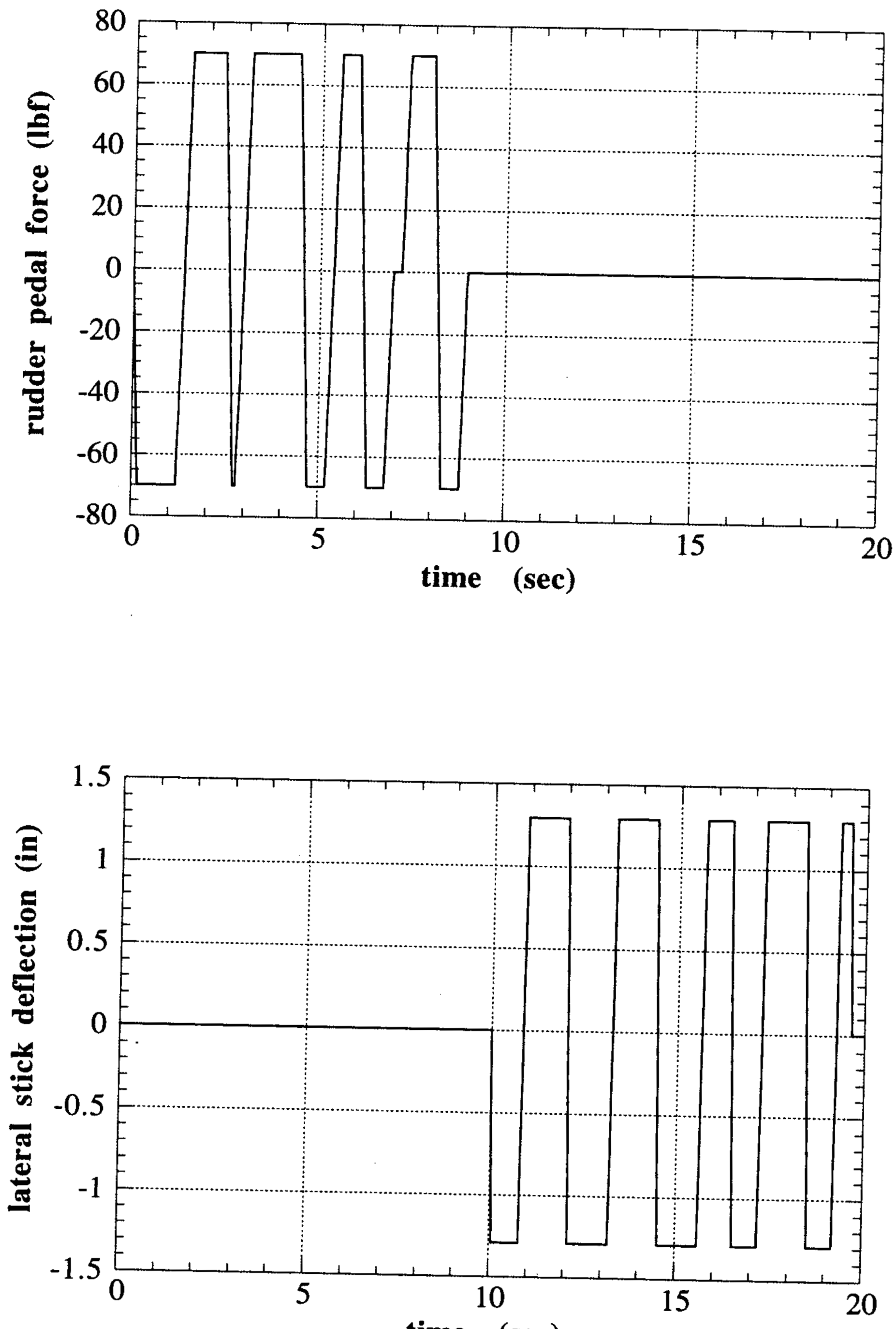
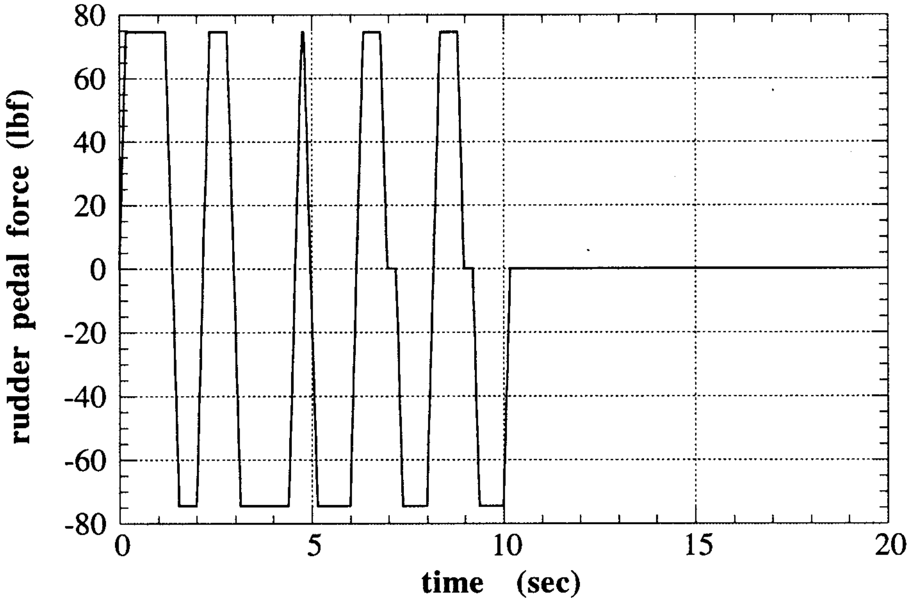


Figure 6 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, $\alpha = 5$ degrees



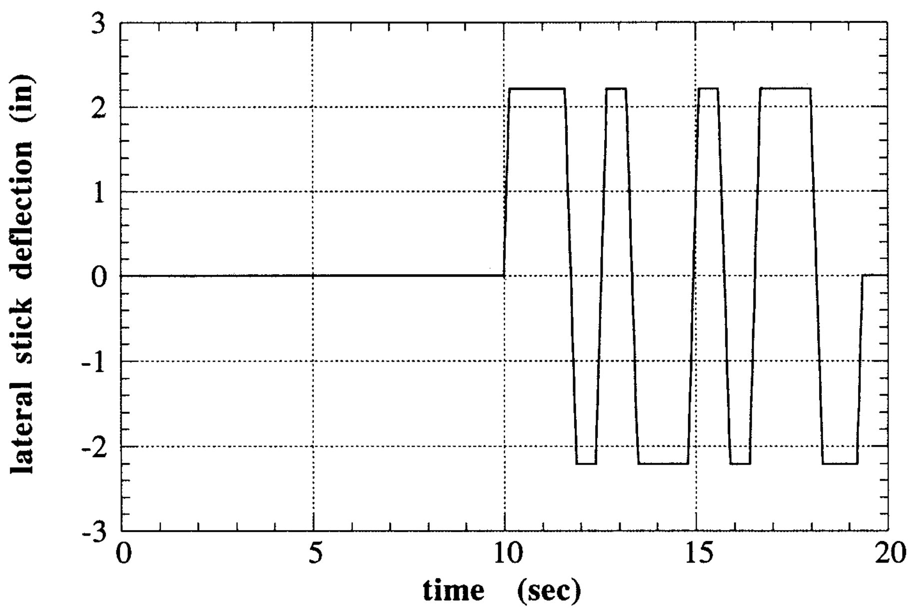


Figure 7 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, $\alpha = 20$ degrees

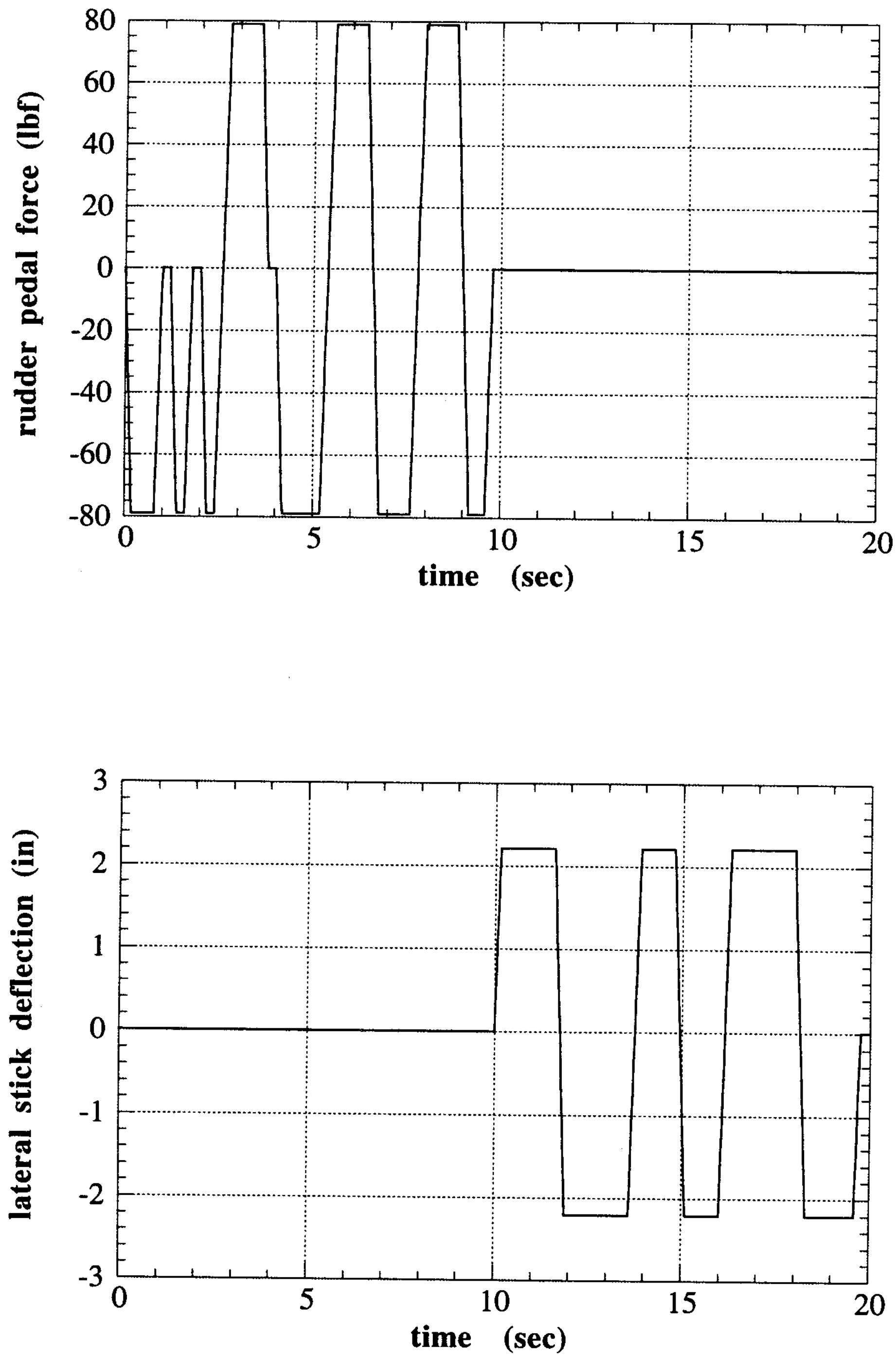


Figure 8 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, $\alpha = 30$ degrees

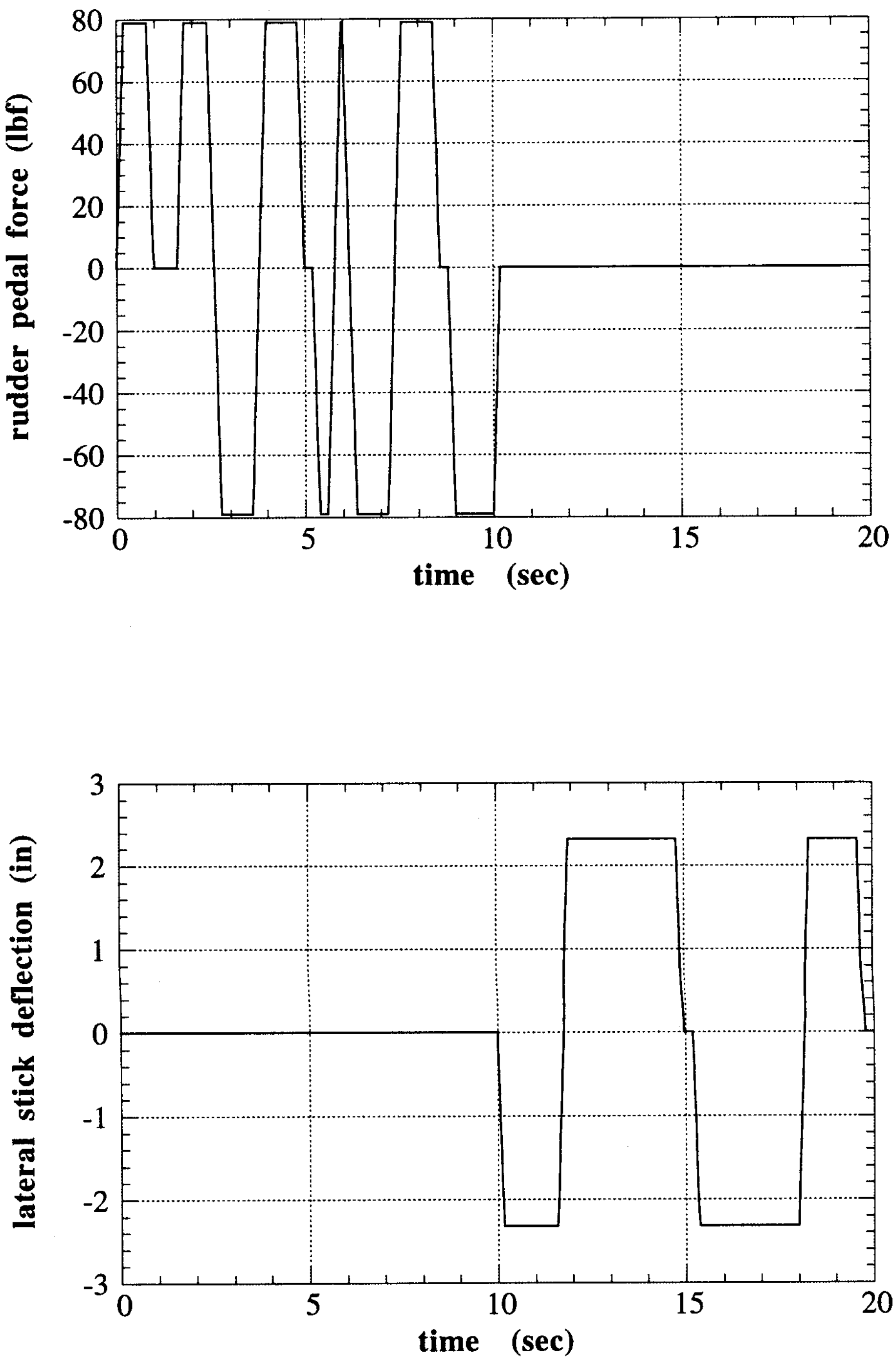


Figure 9 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, $\alpha = 45$ degrees

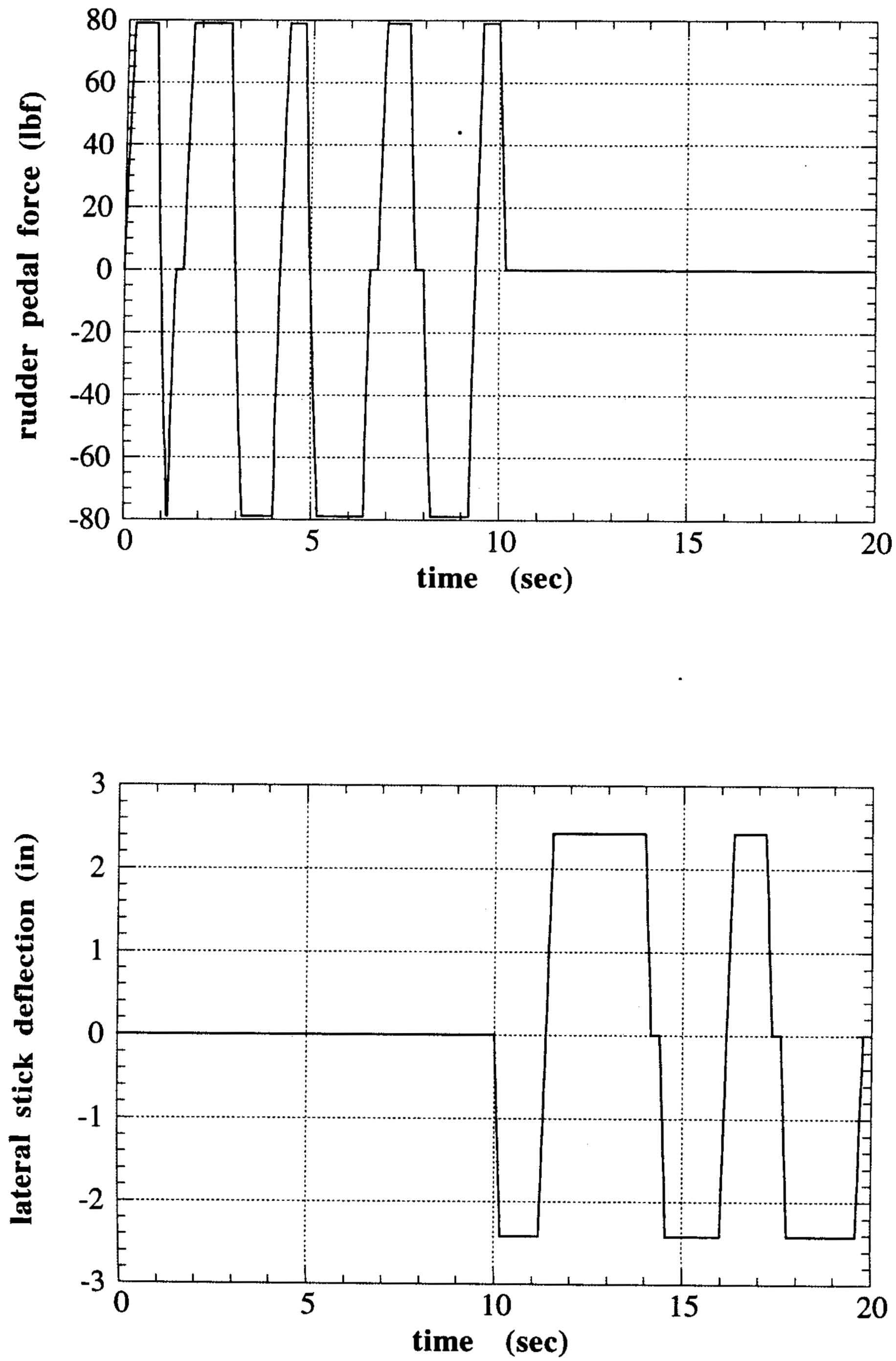


Figure 10 F-18 HARV Optimal Rudder Pedal and Lateral Stick Inputs, $\alpha = 60$ degrees

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Flight test maneuvers are specified for the F-18 High Alpha Research Vehicle (HARV). The maneuvers were design for closed loop parameter identification purposed, specifically for longitudinal and lateral linear model parameter estimation at 5, 20, 30, 45, and 60 degrees angle of attack, using the Actuated Nose Strakes for Enhanced Rolling (ANSER) control law in Thrust Vectoring (TV) mode. Each maneuver is to be realized by applying square wave inputs to specific pilot station controls using the On-Board Excitation System (OBES). Maneuver descriptions and complete specifications of the time/amplitude points defining each input are included, along with plots of the input time histories.

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